

CONSTELLATION X-RAY MISSION AND SUPPORT

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NASA Cooperative Agreement NCC5-368

Third Annual Report

For the Period October 1, 2000 to September 30, 2001

Principal Investigator

Dr. H. Tananbaum

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Prepared for:

**National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland, 20771**

**Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts, 02138**

**The Smithsonian Astrophysical Observatory
is a member of the
Harvard-Smithsonian Center for Astrophysics**

**The NASA Technical Officer for this Agreement is Jean Grady, 740.0, NASA/Goddard
Space Flight Center, Greenbelt, Maryland 20771-0001**

1.0 Introduction

This is the Third Annual Report of work performed by the Smithsonian Astrophysical Observatory (SAO) for NASA Goddard Space Flight Center (GSFC) under Cooperative Agreement NCC5-368¹. The Agreement is entitled "Constellation X-ray Mission Study and Support." Work performed through January 31, 2001 was reported in a supplement to the Second Annual Report. That supplemental report was submitted in order to obtain funding subsequent to March 2001 which has, as the result of prior funding actions become the de facto beginning of the funding year under the Agreement. This report covers the balance of the third year of the Agreement from February 1, 2001 through September 30, 2001. The Agreement as currently configured runs for two more years. When funding is significantly different from the originally approved amounts, SAO submits a revised budget. One such revision was submitted last year and was the basis for funding a portion of the work reported here.

Work continues under the overall direction of Dr. Harvey Tananbaum, the SAO Principal Investigator for the program. Mr. Robert Rasche is the SAO Program Manager and is responsible for day-to-day program management at SAO and coordination with GSFC.

The report summarizes the main areas of SAO activity. Most of the work has been performed jointly with personnel from GSFC and Marshall Space Flight Center (MSFC). Consequently, we do not claim that such activities were carried out exclusively by SAO. Rather, we describe SAO participation in these efforts.

As is appropriate to a Cooperative Agreement, SAO continued to work with GSFC in an integrated team mode. SAO was involved in the overall mission management, technology development, scientific direction, and mission definition. Figure 1 shows the project organization. While formal overall management responsibility resided with GSFC, scientific lead and subordinate responsibilities were shared between GSFC and SAO.

The work performed by SAO is generally consistent with the SAO proposal "Constellation X-ray Mission Study and Optics Development" dated September 1997, which was the basis for establishing the subsequent Cooperative Agreement. The scope of the effort has expanded somewhat to accommodate the needs of the project. The activity in most cases has been a level of effort. Priorities and work progress have been closely coordinated with GSFC throughout the program. Funding limitations constrained the work accomplished during this period.

Nonetheless, a significant amount of work was accomplished. Under the Agreement, SAO performed work in seven major areas of activity. These areas related to:

- Constellation X-ray Mission Facility Definition Team and Study Management
- Science Support
- Spectroscopy X-ray Telescope (SXT)
- Systems Engineering
- Travel
- In-house Management and Coordination

¹ In subsequent text, NCC5-368 is simply referred to as the "Agreement". A Cooperative Agreement is the appropriate vehicle for the close, flexible, and wide ranging interaction between SAO and NASA needed to ensure the success of the Constellation-X project formulation activity.

The following sections discuss work performed by SAO during the reporting period on behalf of the Constellation-X project in each of these areas.

Questions regarding this report can be directed to:

Robert W. Rasche
Smithsonian Astrophysical Observatory
60 Garden St., MS 29
Cambridge, MA 02138
(617)-496-7774
rrasche@cfa.harvard.edu

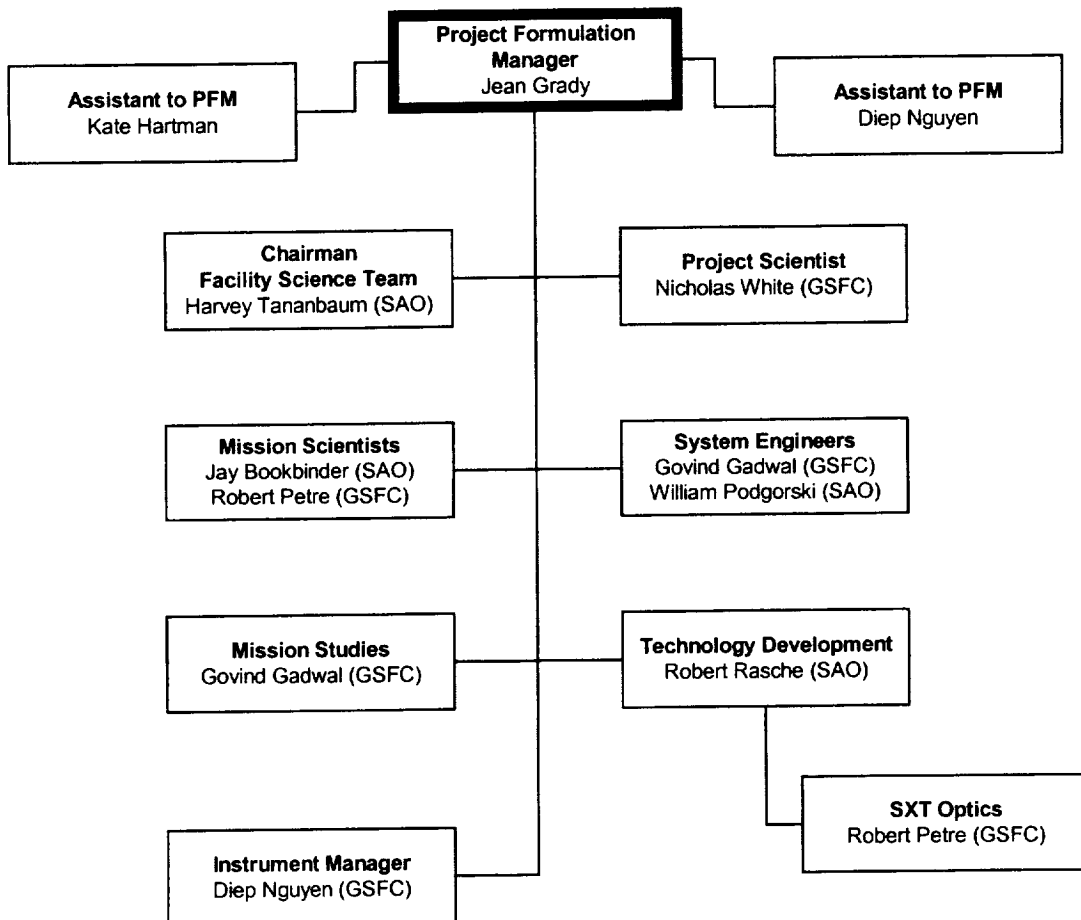


Figure 1
Constellation-X
Project Organization Chart

2.0 Constellation X-ray Mission Definition Team and Study Management

2.1 General Study Management and Coordination

SAO continued to be heavily involved in Constellation-X mission definition and the overall management of the study. Management decisions generally involved the Project Scientist, Dr. Nicholas White (GSFC), the Facility Science Team Chairman, Dr. Harvey Tananbaum (SAO)², the Project Formulation Manager, Ms. Jean Grady (GSFC), and the SAO Program Manager, Mr. Robert Rasche. Frequently the two Mission scientists, Dr. Jay Bookbinder (SAO) and Dr. Robert Petre (GSFC) were also involved.

SAO continued to take the lead role in technical overview and coordination of the SXT Mirror technology development effort while GSFC brought its expertise to bear on overall mission definition with emphasis on spacecraft configurations, subsystem definition, and attitude control. During this period, much of the detailed SXT planning and management migrated to GSFC, due mainly to the start of an organized SXT engineering unit activity and the procurement (through MSFC) of a high precision segment type finish mandrel.

SAO participated in mission definition activities, particularly with regard to thermal control, error budget development, and developing both mission requirements and resultant flow-down requirements. SAO personnel brought extensive and relevant experience from CHANDRA, HEAO, TRACE, HST, and other programs to the Constellation-X mission definition work.

Drs. White and Tananbaum had primary responsibility for scientific management with support from Drs. Bookbinder (SAO), Weaver (GSFC), and Petre (GSFC) and, occasionally, others. This included coordination with members of the Facility Science Team, interactions with NASA Headquarters and the scientific community at large, as well as participation in the Constellation-X Study Team meetings that were held approximately every two weeks at GSFC. Other special meetings were also supported.

The SAO management team participated aggressively in establishing plans, budgets, presentations, and priorities. This has been and continues to be an on-going and more or less continuous activity.

2.2 Technology Development Management and Coordination

Under the Agreement, SAO carries out an important role in managing and coordinating technology development for Constellation-X. That role continued through the reporting period. The organization chart on page 2 shows Mr. Rasche responsible for coordinating technology development.

As things have turned out, work related to the SXT took most of Rasche's available time although he kept himself informed of instrument technology developments, particularly with regard to the micro calorimeter work where considerable funds have been allocated. Diep Nguyen at GSFC who has joined the project at GSFC as Instrument Manager has more than taken up the slack in this area. The SAO role has been primarily to provide expertise, coordination, and general overview to the instrument development work. SAO supports all project teleconferences related to instrument technology.

² Because Constellation-X is a consolidation of their individually proposed and accepted programs into a single program, Drs. White and Tananbaum function as equal Co-Principal Investigators although they have well-defined and separate formal responsibilities.

SAO also took part in a series of conferences with the various Constellation-X IPT team leaders. During these discussions, plans and budgets were aggressively reviewed and this resulted in a good basis for going forward.

2.3 Reports and Presentations

SAO personnel were involved in preparing and reviewing the Constellation-X part of the State of the Universe annual report presentation for 2001. SAO worked closely with GSFC throughout the effort to help establish the outline of the presentation as well as the development of specific view graphs. Dr. Tananbaum attended the presentation to Dr. Weiler at NASA Headquarters.

SAO personnel developed and made presentations at many meetings. These meetings included the biweekly team meetings at GSFC, the FST meeting, splinters and special meetings arising out of the FST meeting, and technical interchange meetings, particularly those related to the SXT Mirror Assembly.

SAO, GSFC, and MSFC use MS PowerPoint in the current version so that charts can be worked on by each group and can be easily sent back and forth several times within a working day. This is another example of the close and highly interactive operation that characterized much of the joint Constellation-X effort.

2.4 Mission Studies

SAO personnel also made direct technical contributions to the ongoing mission studies at GSFC and to discussions and trades related to mission operations and instrument accommodation. This helps ensure that relevant CHANDRA (AXAF) experience (which is ongoing) in these areas is transferred to the Constellation-X program in an effective and continuous way. These contributions have tended to be related to systems engineering issues — an SAO strength (see Section 5).

3.0 Science Support

3.1 Chair of the Facility Science Team (FST)

Under the Agreement, SAO provided and continues to provide the Chair of the Constellation-X Facility Science Team, the group of scientists who help guide the program with regard to scientific objectives and needed capabilities. Dr. Tananbaum serves as Chair and is assisted by the Mission Scientist, Dr. Bookbinder and other members of the FST from several institutions and, of course, the Project Scientist, Dr. White and his science colleagues at GSFC.

During the period of performance, Dr. Tananbaum was a point of contact for both general FST members as well as for the leaders of the instrument technology teams. This activity was closely coordinated with Dr. White at GSFC who carried out a similar function. In general, Dr. White was more involved with the Government members of the FST and Dr. Tananbaum worked with FST members from non-Government organizations.

3.2 Mission Scientist

As required by the Agreement, SAO provided the expert services of Dr. Jay Bookbinder who filled the position of the Mission Scientist from SAO. His GSFC counterpart is Dr. Robert Petre.

Dr. Bookbinder participated in team meetings at GSFC and SAO and was an active and direct technical contributor to the SAO team. He also carried out special assignments for the FST Chair, Dr. Tananbaum. Dr. Bookbinder brought substantial and relevant expertise and experience from TRACE and other NASA programs. Working with others, he continued to further define and document the Constellation-X Top Level Requirements. A significant amount of both analysis and coordination with others was required to carry out this activity.

3.3 Representation at Various Scientific Meetings

Constellation-X scientists from SAO attended and participated in scientific meetings throughout the period. Their participation at these events helped to promote the Constellation-X program by providing information about it, answering questions, and soliciting inputs to help ensure a balanced, effective, and significant science program. This activity involved Drs. Tananbaum and Bookbinder.

3.4 Facility Science Team Meeting

A meeting of the FST was held at SAO on May 3-4, 2001. SAO did the bulk of the organizing and provided logistics including travel arrangements for non-foreign attendees. Scientific, programmatic, and technical issues were covered at the meeting.

Dr. Webster Cash of the FST described an "off plane" approach to high-resolution gratings. Provided the gratings can be made to adequate ruling densities, the off-plane approach advocated by Dr. Cash offers a number of advantages relative to the in-plane transmission gratings which are the current Constellation-X baseline. It was the sense of the FST that the feasibility of off-plane gratings should be evaluated. The action was taken by SAO in conjunction with Dr. Cash. Dr. Bookbinder of SAO took the lead in coordinating this activity. He and Dr. Podgorski (SAO) independently developed the equations of performance to ensure good understanding and insight into off-plane grating performance and their relative merit with respect to the in-plane gratings.

4.0 Spectroscopy X-ray Telescope (SXT)

During the reporting period, more SAO effort was applied to the Spectroscopy X-ray Telescope and, in particular, to its X-ray mirror³ than to any other task. SAO performed SXT related work in seven main areas:

1. SXT Management and Coordination
2. SXT Mirror Module Design
3. SXT Mirror Technology Study Support
4. SXT Mirror Assembly Plans
5. SXT Error Budget Development
6. Segment Mirror Mandrel Procurement
7. Flight Mirror Development Planning

4.1 SXT Management and Coordination

Working with the concurrence of the Project Formulation Manager at GSFC (Jean Grady), SAO provided extensive oversight and direction to the Constellation-X SXT mirror definition and development. This activity included but was not limited to:

- Participation in numerous status review and planning teleconferences
- Informal tracking of SXT work progress at MSFC, GSFC, and SAO
- Evaluation and informal reporting of progress to GSFC Constellation-X project office.
- Development and evaluation of work plans and budgets
- Formulation and presentation of recommendations for future plans and priorities
- General overview of SXT work

4.2 SXT Mirror Module Design

SAO continued in-house concept and analysis studies related to SXT segmented mirror concepts. Analytical work was passed from Henry Bergner to William Davis who now provides essentially all of the detailed structural analysis related to the SXT engineering unit design. In this role, Davis works closely with his GSFC counterparts and participates in telephone conferences and on site meetings at GSFC.

As work on the SXT Engineering Unit began, the work was tracked and evaluated on a continuous basis.

4.3 SXT Mirror Technology Study Support

SAO provided extensive support to many aspects of the SXT technology studies at both MSFC and at GSFC. This work was both analytical and experimental.

³ Technically the term Spectroscopy X-ray Telescope refers to the complete X-ray telescope. In practice, the term SXT and SXT Mirror have, unfortunately, come to be used interchangeably. The greater portion of SAO activity related to the SXT was directed at the X-ray mirrors per se.

Analytical work related to a variety of issues including analysis of support concepts, effects of epoxy shrinkage, and deformations due to metrology setups. SAO also studied the effect of 1g forces on a variety of configurations.

4.4 SXT Mirror Assembly Plans

Work related to SXT Mirror Assembly planning accelerated somewhat during the reporting period as issues became clearer and we realized that the technology selected might well be driven by flight mirror development considerations. The effort included plans for ongoing work as well as initial flight program planning and definition. This work was closely coupled to the work reported in Section 4.7.

SAO continued to work at a low level of effort on a detailed baseline plan for the SXT Flight Mirror Assembly development. The plan begins with current work on an Engineering Model segmented mirror and continues through the delivery and integration of the flight mirror assemblies. Effort to date has concentrated on identifying tasks and task sequences and the relationships of these to each other. We also started to revisit cost estimates.

4.5 SXT Error Budget Development

Work on the SXT error budget continued during the reporting period although because of both personnel and funding conflicts, the effort was limited. A first order error budget was created for the design put forth by Cohen et al, but for a variety of reasons, that design evolved into a different concept with its own set of error components.

4.6 Segmented Mirror Mandrel Procurement

A segmented mirror mandrel procurement action is currently under way. MSFC will let and manage the contract. SAO provided draft text both for the synopsis and for the subsequent solicitation. Van Speybroeck and Rasche will participate in the selection process.

4.7 SXT Flight Mirror Program Planning

Useful SXT mirror technology will almost certainly be constrained by at least four factors related to flight mirror development rather than mirror technology per se. These factors are:

- Availability of required infrastructure and expertise
- Ability to obtain required infrastructure where none exists
- Corporate willingness to accept a contract for large flight or even prototype mandrels, particularly when compared with other business opportunities.
- Technical concerns related to size and mass (mainly a full shell concern)

5.0 Systems Engineering

SAO continued to provide systems engineering support to the Constellation-X project. Work was mainly concentrated in five areas:

- Thermal control
- Requirements and requirements flow down development
- Opto-structural analysis of segmented SXT concepts
- System error budgets

5.1 Thermal Control

SAO and GSFC established a close working interface in the area of both instrument and overall system thermal control. In particular, David Boyd and Mark Freeman at SAO and Wes Ousley at GSFC have continued to review the system as it develops and coordinate closely with each other. Effort by SAO in this area was limited primarily by available funding. SAO restarted work related to SXT Mirror Assembly temperature control.

5.2 Requirements and Requirements Flowdown

The Constellation-X Top Level Requirements have been defined although a few of them may be modified. Recent work has emphasized establishing the so-called Flow Down Requirements on the various Constellation-X subsystems that a consequence of the top level requirements. This work is being done primarily by Drs. Bookbinder and Podgorski with the participation and review of others as appropriate. This work included analysis and research related to establishing numerical values for the various requirements.

5.3 Opto-Structural Analysis of Segmented SXT Concepts

As indicated in Section 4.2 provided optical and structural analysis support to the emerging SXT Engineering Unit effort. In addition, much of the relevant past documentation related to designs, assembly and alignment schemes was distributed to everyone at GSFC, MSFC, and SAO who might have an interest in the SXT Engineering Unit. The intent of this distribution was to a.) provide a reference, b.) identify issues that need to be considered in any design, and c.) present an approach that seems (perhaps with tweaking) to have merit and to make certain that people on the program would have no excuse for not having seen any of the subject material.

5.4 System Error Budgets

Some, but not much work was done during the reporting period to extend system error budgets. That more work was not done in this area was due mainly to funding limitations. This important activity will receive much more attention in the coming year, particularly those components associated with both the full shell and segmented SXT mirror assembly design concepts.

6.0 Travel

The Agreement provided funding for frequent program travel. Most of the travel was between SAO and either GSFC or MSFC.

With few exceptions, a Constellation-X Study Team meeting was held at GSFC every other week between 1:00 p.m. and 3:00 p.m. with splinter meetings on either side of this fixed time. This arrangement allowed SAO personnel to travel from Boston to GSFC and return on the same day with substantial savings in lodging and per diem costs. These meetings were usually attended by at least two SAO persons and occasionally by three or four if required by either the meeting agenda or related splinter meetings. Whenever possible, splinter meetings were set up on the same day as the team meetings. These meetings were usually technical interchange meetings that took the form of informal working meetings. However, some of the splinter meetings were management review and planning meetings.

When appropriate, Rasche visited GSFC for two days, one day for the Study Team Meeting and related splinters and the second day (either before or after) for informal management discussions with Jean Grady and others. This has worked quite well and will be continued over the coming year. Other SAO personnel generally have made a one-day trip to support the Study Team Meeting and sometimes related splinter meetings.

SAO staff working on SXT mirror technology traveled to MSFC. These trips related to segment mandrel procurement. Additional travel was required by SAO engineers to meet at GSFC relative to segmented mirror work.

7.0 In-House Management and Coordination

In addition to the direct participation in the Constellation-X project summarized above, SAO carried out housekeeping, coordination, and planning activities at SAO. This work related to the orderly operation of the SAO Constellation-X team.

These activities included:

- Cost planning, tracking, analysis, and control
- Personnel evaluation inputs
- Purchasing and logistics
- Coordination and information meetings
- Travel arrangements

SAO did not produce any stand-alone formal documents as such during the period of performance. Analyses, error budgets, area vs. energy plots, and requirements were developed and documented as informal documents, particularly by Bookbinder, Cohen and Podgorski. These were distributed in a timely way as attachments to e-mail messages. The Constellation-X Top Level Requirements document and its companion Flow down Requirements document are still in process and will, in any event, be released as project documents.

